CHAPTER 3

UPLIFT AND LEAKAGE

Section I. Uplift

3-1. Purpose. Measurement of uplift pressure intensities at several points under a structure are made to check the validity and accuracy of the design assumptions pertaining to uplift, and to provide information for future designs as to the area1 extent and magnitude of hydrostatic pressures. The practice of attempting to determine uplift pressures by installing pressure gages on foundation drains is improper and should be avoided, since, determination of pressure at a single point on a gradient is of little value, and the actual uplift pressure pattern is modified when a foundation drain is prevented from functioning in its normal manner. For converse reasons, uplift cells should not be utilized for leakage determinations.

3-2. Description.

a. Uplift Cells. Uplift pressure cells are normally placed on the foundation rock and located 15 to 20 ft apart along lines normal to the axis of the dam as shown in Plate No. 3-1. Where the transverse distribution of uplift pressures is to be investigated also, up to five or more separate lines of cells may be placed under one monolith. Except for unusual foundation conditions, uplift instrumentation facilities are usually confined to one or two of the large monoliths.

b. Standpipe Type Cell. The simplest and most widely used type of uplift cell consists of a gravel-filled wooden box installed over a shallow drilled hole, containing a pipe tee and two short lengths of perforated pipe. Plain pipe runs from the perforated pipe in the collector box to the reading station in a gallery wall, where the pipe is capped with a gage adapter coupling and a shutoff cock. Pressure heads at the cell exceeding the elevation of the reading station are measured by Bourdon-type gages. Pressure heads at the cell less than the gage elevation are determined by removing the gage adapter and sounding to the water surface in the pipe or by reading the water level by one of the other methods available such as the water level indicator mentioned in paragraph 3-10. Typical details of the box and piping are shown on Plate No. 3-1.

c. Diaphragm Type Cell. This type is cylindrical in shape, with a porous disk in one end and tubes or electrical cable entering the other. Immediately behind the porous disk is an impermeable diaphragm, the deflection of which is measured by strain gages, or either air or oil pressure, depending on whether the piezometer is classified as electrical or pneumatic. An example of the first type is the Carlson pore pressure cell described in paragraph 2-6, and the second type is the Gloetzel pressure cell described in paragraph 2-31e. The Carlson pore pressure cell has been the most commonly used in the U.S. for installation in concrete dams. See Figures 2-5 and 2-8.

3-3. Installation.

a. Standpipe Type Cell.

(1) Collector Box. As soon as foundation excavation and cleanup has been completed, the cell locations are marked and the shallow holes drilled. The pipe tee, perforated pipe sections, and a length of plain pipe are put in place and the hole filled with clean No. 4 to 3/4-in. crushed rock or gravel. A wooden box is built to conform with the foundation surface in that area, filled with crushed rock or gravel, and the top nailed in place. On the day prior to placing the lift concrete, the box cell is covered with hand-placed mass or face concrete (depending upon the location of the cell) to hold the box in place during subsequent concrete operations.

(2) Pipe Runs. Lengths of plain galvanized pipe are added to the section protruding from the cell box to an elevation above the top of the first lift. Subsequent lengths are added as successive concrete lifts are placed. Pipe runs are placed with an upward slope of about 1/4-in. per foot from the cell to a point directly beneath the reading station, and thence vertically upward to the gallery recess. Pipe assemblies may be held in position during concrete placement by welded angle-iron or pipe frames embedded directly in the concrete together with the pipe runs, as in Figures 3-1 and 3-2. Large radius bends are permissible for slight changes in direction; but conventional pipe elbows should be used for abrupt direction changes. Normally pipe runs will not cross contraction joints, but when necessary to do so, "dresser" expansion couplings should be provided. All threaded pipe connections should be made leakproof by painting the threads with white lead or similar plumbing compound.

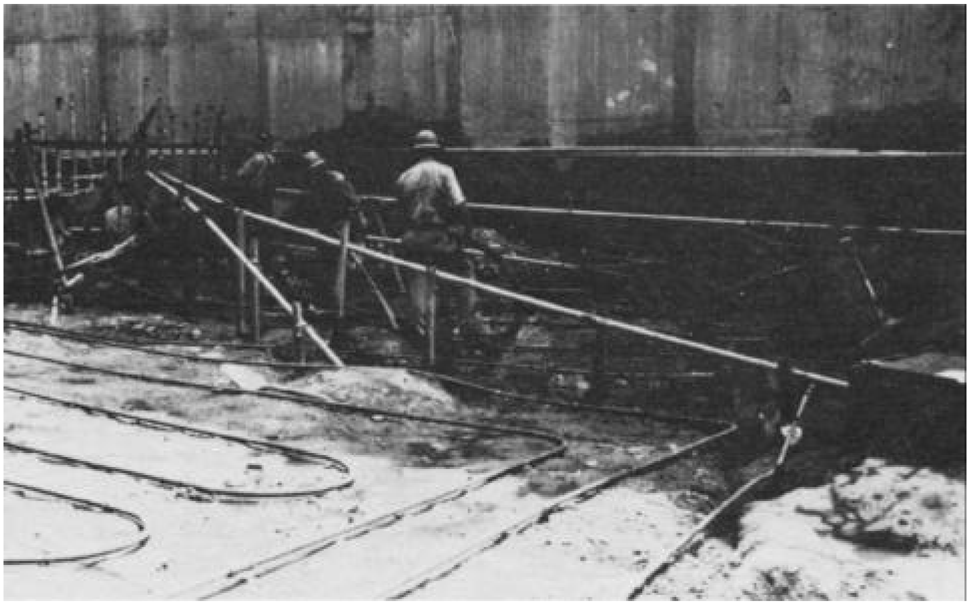


Figure 3-1. Uplift Cell and Sloping Pipe Assembly (Courtesy of the Tennessee Valley Authority).

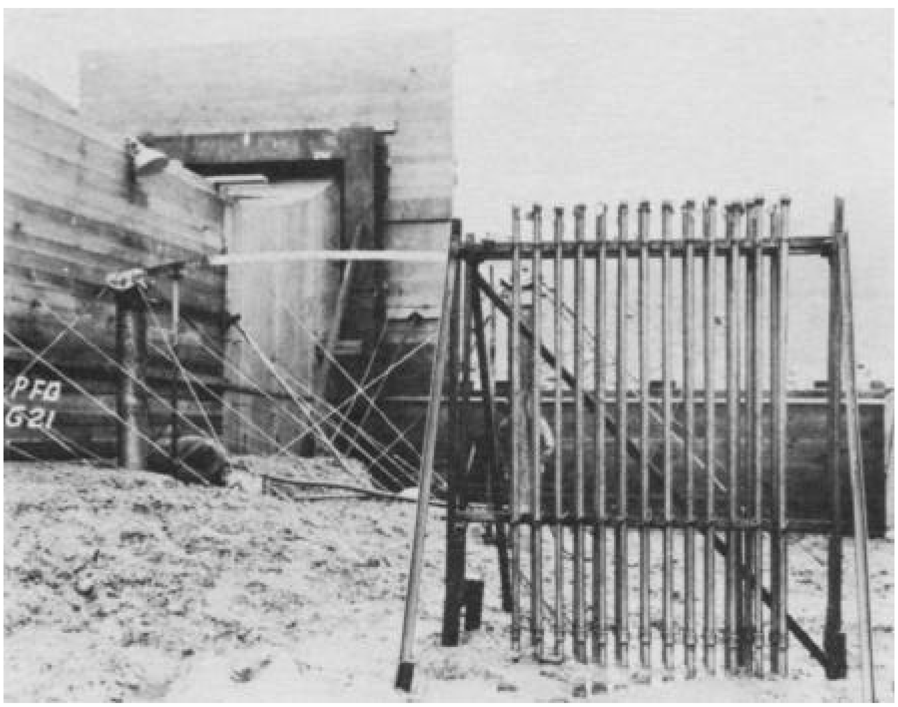


Figure 3-2. Vertical Pipe Runs from Uplift Cells.(Photo by WES)

(3) Readout Station. The exposed end of each uplift pipe at the reading station should be capped with a shutoff cock and gage adapter coupling. A typical station is shown in Figure 3-3. This will enable a portable pressure gage of suitable capacity to be temporarily attached to a pipe for a pressure reading, thus reducing the number of such instruments required at a project and avoiding the corrosion problems associated with installed gages in damp galleries. A set of portable gages should consist of three high-quality commercial type gages. One set composed of a low, an intermediate, and a high capacity gage covering the range from minimum to maximum possible pressure heads is usually adequate. Where uplift head is below the elevation of the reading station a graduated tape with a small float will be necessary. Also a number of electrical type probe devices are commercially available, some of which are described later in this chapter. When the probe contacts the water surface, the circuit is closed and registered on an ohmmeter. The length of wire is measured with a tape if graduation marks are not made on the wire. Metal identification markers should be welded or otherwise permanently fastened to each uplift pipe extending into the gallery recess.

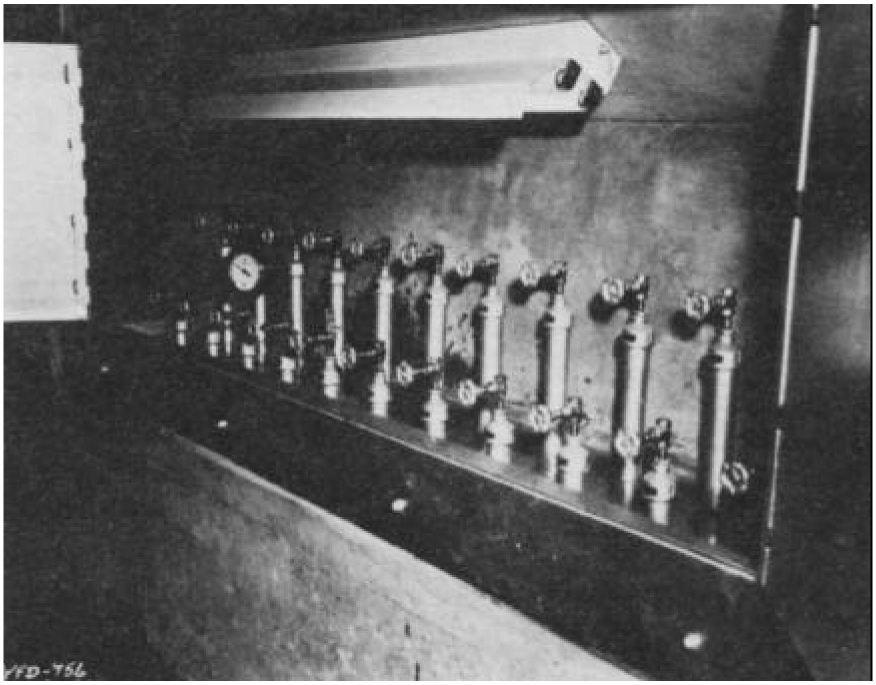


Figure 3-3. Uplift Cell Terminal Reading Station. (Photo by CE-WES)

b. Diaphragm Cell.

(1) Preliminary Precautions. The installation of this type of gage must be carefully done in order to prevent damage of the instrument. Before taking the pressure cells to the site for placement, the porous plug of the Carlson gages should be removed and the space between the plug and the diaphragm filled with petroleum jelly. After all foundation excavation and cleanup has been completed the cells with attached cables or tubes should be securely fastened to the rock. A day before placing the lift concrete, a small amount of mass concrete should be hand placed and tamped around the cell. Vibrators should not be used because of the possibility of cement mortar clogging the porous disk of the cell. When the mass concrete is placed, care should be taken to tamp the concrete around the conductor cable to prevent it from providing a leakage path to the cell and thus alter the pressure being measured.

(2) Reading Station. The station for a Carlson type pore pressure gage should be identical to that required for the Carlson stress meters and strain meters, as discussed in paragraphs 2-2 to 2-5. The station for other types of meters should be designed to use the reading equipment required by the type of gage installed. Metal identification markers should be permanently fastened to each of the cables or tubes from the cell in the foundation.

3-4. Collection of Data.

a. Standpipe Cells.

(1) Elevations. At the time the cells are installed and the pipe runs placed, elevation of each uplift cell and of the 90° bend beneath the reading station should be recorded. The exact position of each cell as finally installed should be shown on a copy of the final foundation rock elevation geologic map.

(2) Shutoff Cock. Where the pipes at the reading station are capped, the shutoff cocks should be left open until the hydrostatic pressure gradient exceeds the reading stationelevation as evidenced by water discharging from the pipe. After the entrapped air has been completely expelled from a pipe, the shutoff cock should be kept closed except during the time the pressure gage is attached.

(3) Readings. To make a pressure reading, slowly open the shutoff cock slightly to determine if hydrostatic pressure exists at the reading station and to allow any accumulated air or gas to escape. If a positive pressure is apparent, close cock immediately, attach a portable Bourdon-type gage and slowly open the cock. Allow a few minutes for the pressure in the pipe and gage to become stabilized and then record the indicated pressure. Where the general magnitude of the pressure is unknown, it is best to initially attached the maximum capacity gage to determine the approximate pressure, replacing it with one of the lower capacity gages of the set if feasible for making the pressure reading. Where the uplift head is below the elevation of the reading station, the shutoff cock fitting must be removed at each reading and the free water level in the pipe determined by sounding. A graduated tape with a small float attached will be found suitable for this purpose. Additionally, the water level can be determined through the electrical gage mentioned in paragraph 3-10.

(4) Field Data Sheets. In order to provide a uniform method for recording and presenting uplift data, and to facilitate analysis of the results, water surface elevations and pressure heads should be recorded directly on ENG Form 2254, Foundation Uplift Pressures, reproduced here in Plate 3-2. When the pressure at the standpipe reading station is positive, the pressure gradient is obtained by multiplying the reading in pounds per square inch by 2.308 to obtain the value in feet of water. This value is added to the elevation of the reading station to obtain the hydrostatic uplift pressure gradient value. When the standpipe gage does not show a pressure, and the pressure head elevation is determined by plumbing, the distance measure from the reading station to the water level is subtracted from the reading station elevation to obtain the hydrostatic uplift pressure for recording on the form, With the reservoir water surface and tailwater elevations also recorded on the field reading sheet, all information is readily available for plotting pressure histories, as shown on Plate No. 3-3, and hydrostatic gradients on Plate No. 3-4, without further calculations. Leakage data is obtained in many forms, depending upon the manner with which the flow rate is measured. The results should be expressed in gallons per minute.

(5) Processing of Data. Computation of the field data should be made and filed in the field office. Copies should be sent to the Engineering Division for evaluation.

b. Diaphragm Type Cell. The technique for observing this type of piezometer should be in accordance with the recommendation of the manufacturer. If the Carlson type is used, the readings should be obtained in the same manner as for strain and stress meters discussed in Chapter 2.

3-5. Reading Schedules. The observation program should be started during the construction period, preferably 3 to 6 months prior to final closure. Readings at monthly intervals will provide adequate information on the uplift conditions existing before the effect of the reservoir head becomes apparent. During the initial filling of the reservoir the monthly readings should be increased to once every one or two weeks. After the initial filling of the reservoir and stabilization of the water table in the vicinity of the dam, uplift pressures will change relatively slowly with respect to time, even for the more permeable foundations. For that reason the reading interval may be increased considerably. These routine observations should be supplemented by additional weekly measurements during each period of high reservoir level which is expected to equal or exceed the maximum pool level previously attained. The special measurements should continue for several weeks past the time of the high reservoir level. A complete record of pool and tailwater elevations, either from an automatic recorder or routine daily observation is necessary and should be recorded at the time of piezometer observations.

Section II. Leakage

3-6. General. Periodic measurement of leakage from foundation drains, joint drains, and face drains serve as an indication of the adequacy of the foundation grout curtain, functioning of the drains and reveal when and where remedial measures may be required. Observations of leakage from contraction joints, lift joints, and cracks provide a means for judging the quality of workmanship or construction practices, as well as disclosing the necessity for corrective measures to preserve the integrity of the structure. The main drainage sump may be utilized as a collecting and gaging point for all flows. Two types of gages are available: vee-notch weirs and critical depth meters.

3-7. Vee-Notch Weir.

a. Description. Measurement of flow in selected lengths of gutters may be accomplished by inserting vee-notch weirs to measure total cumulative flow above each weir. Figure 3-4 shows a weir with gutter design for ease of installation. Individual drains or joints leaking excessively may be gaged separately.

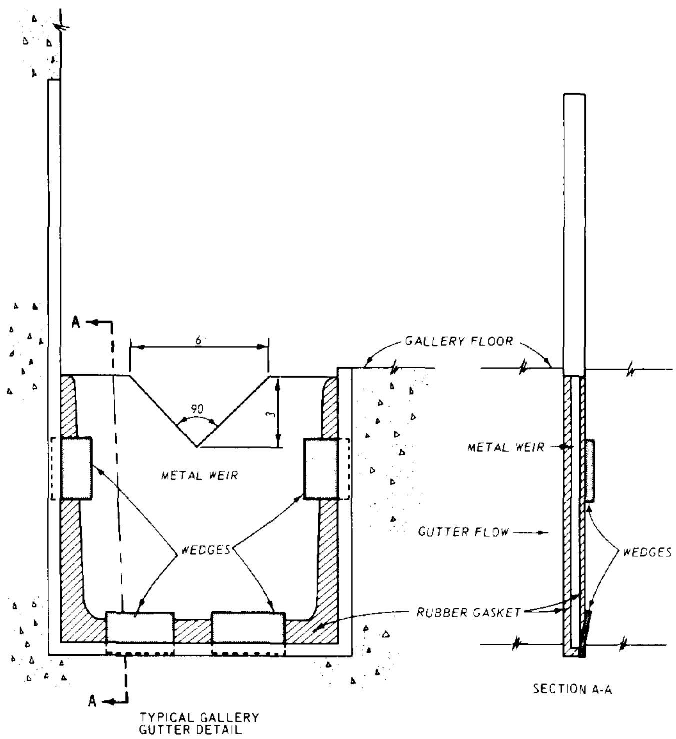


Figure 3-4. Vee-Notch Weir. (Prepared by WES)

b. Collection of Data. Total leakage into the interior drainage system of the structure may be calculated by one of the following methods.

(1) The on-off operation chart of the sump pump and the capacity of the sump between the float operating limits.

(2) A simple mechanical counter actuated by a lever arm fastened to the float stem or line, to indicate the number of fill-pump cycles over a period of several hours or days.

(3) Manually timing the water level rise in the sump,

(4) Measuring the head above the base of a vee-notch weir with a hook gage or scale at one or more locations in the gallery gutters, and the flow rate determined from standard hydraulic tables. Flows from individual foundation drains, vertical face, and joint drains discharging at excessive rates can be determined by measuring the weight or volume of water discharged over a short known time period.

c. Data Sheets. Since the manner of making leakage measurements is dependent upon the type and arrangement of interior drainage facilities, no standard data form has been established. Survey field books or forms developed in the project office are satisfactory, providing arrangements are made for retaining the results in a permanent file for comparison with subsequent leakage data.

d. Reading Schedules. Measurement of excessive individual drain flows and of total leakage should be made at least twice yearly. One measurement should be made at a high pool level and one at the minimum pool level. Where suitable facilities exist for determining total leakage rates with the expenditure of little effort, such as from automatic sump pump operation records, measurement of flows at intervals as short as one week (or even continuously) may prove to be of value. Semi-annual measurements may be reported in tabular form with pool and tailwater elevations given for the data of measurement. It has been found helpful to identify the location of individual measurements if the table is beneath a longitudinal section of the dam with all monoliths shown and numbered.

3-8. Critical Depth Meter.

a. Description. A flow meter that functions on the principle of measurement of the backwater curve established when water flows from subcritical velocities to critical velocity in a weir is marketed by Neptune UES, 7070 Commerce Circle, Pleasanton, California, 94566. The meter shown in Figure 3-5 consists of a U-shaped flume that fits in conduit or gutter and a monitoring power source.

b. Collection of Data. Data are automatically recorded on a strip chart that measures flow versus time. It also has a counter that measures total flow past the flume. The recorder prints through the impinging action of the stylus driven by a clamping bar against pressure sensitive paper. Its presentation is a series of dots appearing as a continuous line. The recorder can be powered by either 12v DC current for remote installations or 120v-60 Hz in continuous operation.

c. Reading Schedules. The flow can be monitored continuously when excessive leakage is apparent or it can be monitored at specific yearly intervals as outlined in paragraph 3-7d.

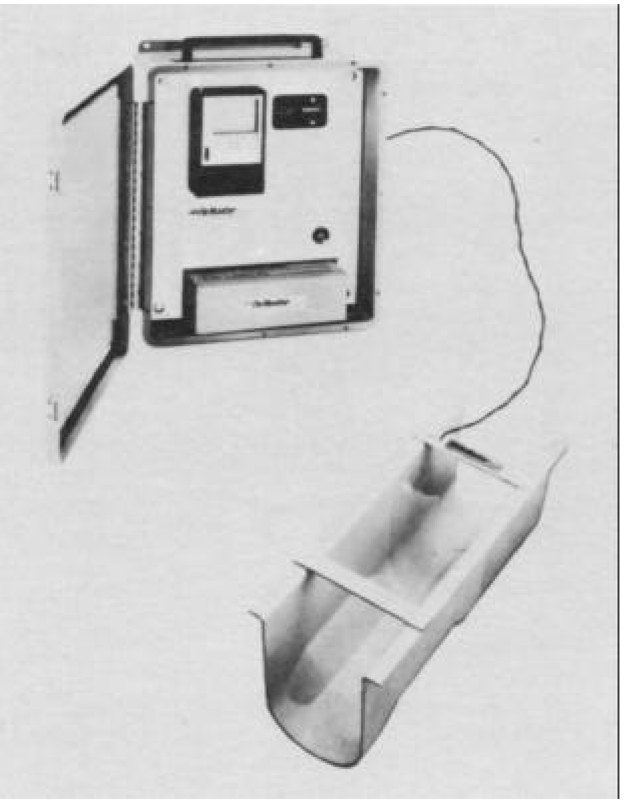
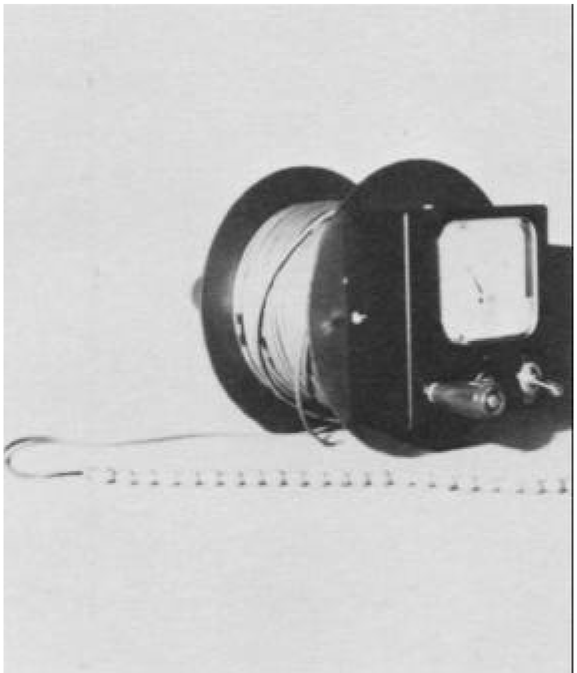


Figure 3-5. Neptune UES Critical Depth Meter (Courtesy of Neptune UES, Inc.).

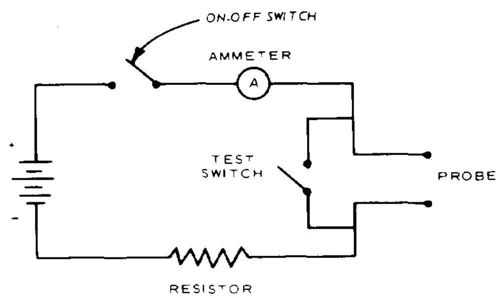
Section III. Supplemental Instruments.

3-9. General. There are some electrical and hydraulic instruments that can also be useful on structures for monitoring water height in piezometer standpipes, pressure under stilling basin slab, and pore pressure. Some of the instruments can be permanently installed and monitored with a portable readout device or with an automatic data acquisition system.

3-10. Water Level Indicator. Electronic water level indicators are useful in monitoring the level of water in the uplift pressure cell standpipe; The Soiltest DR-760A Water Level Indicator, shown in Figure 3-6a, is a self-contained, portable, transistorized instrument for determining water levels in boreholes to depths of 300 ft. Other models are available for greater depths. The high strength, 1/8-in. diameter electrical cable is mounted on a 6-in. diameter steel and plastic spool and has interval markers every 5 ft. The weighted probe assembly keeps the cable taut as it is lowered into the hole. The instrument has a test button, indicating meter, battery, and on-off switch. The simplified circuit is shown in Figure 3-6b. When the probe makes contact with the water, continuity is established, current flows in the circuit, and the ammeter indicator deflects from 0 to full scale.



a. Soiltest Model DR-760A



b. Simplified Circuit

Figure 3-6. Water Level Indicator (Courtesy of Soiltest, Inc.).

3-11. Vibrating Wire Piezometer.

a. Description. The IRAD vibrating wire piezometer shown in Figure 3-7 is designed to provide remote digital readouts of water pressure in fully and partially saturated natural soils, in rolled earth fills, and on the interface of retaining structures. It is particularly useful for hard to monitor spots, such as under the floor of a lock chamber. The vibrating wire gage exhibits very small time lags, an ability to measure negative pressures, high sensitivity and reliability, and transmission of signals as a frequency over long lead-wire lengths. It can be buried in fill during construction, sealed in boreholes after construction, and driven directly into loose ground from the surface (provided the appropriate head design is used). A major application is to upgrade standpipe installations by lowering the piezometer to a fixed point and measuring head pressure directly from a remote readout station.

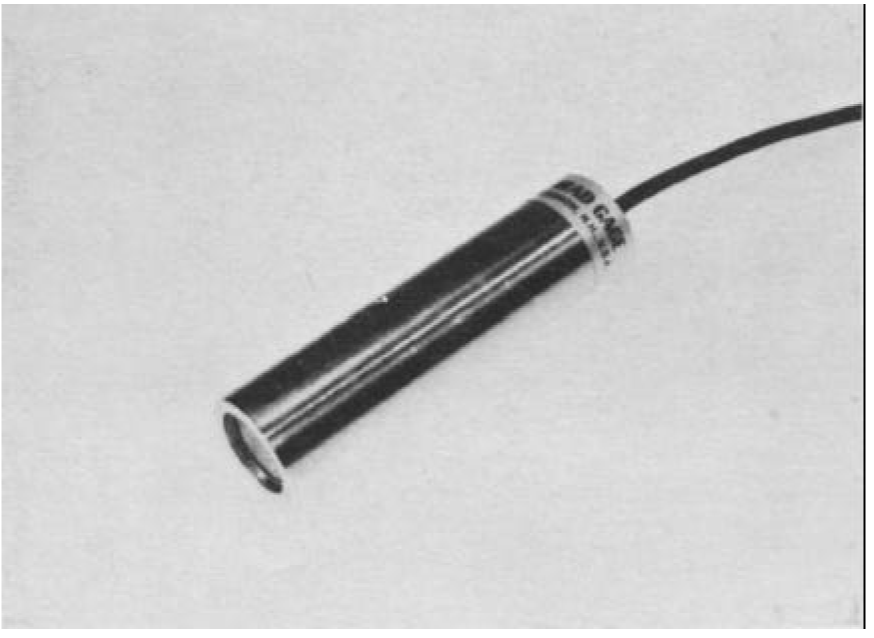


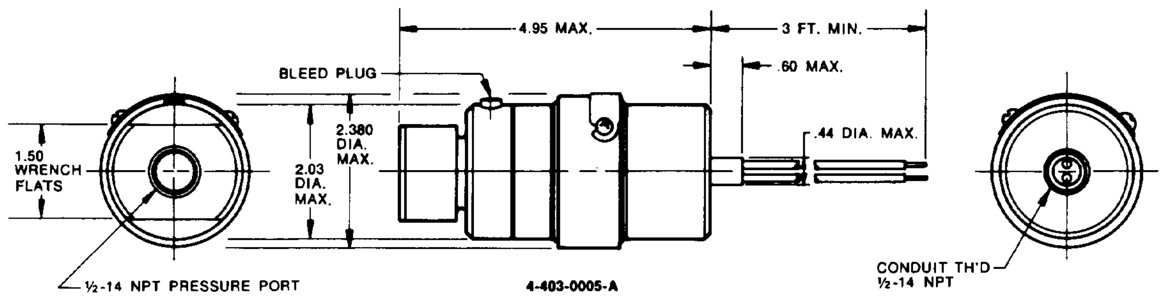
Figure 3-7. IRAD Vibrating Wire Piezometer (Courtesy of Irad Gage, Inc.).

b. Principle of Operation. Water that enters the gage through a filter stone exerts a pressure against the face of a diaphragm. The resulting deflection changes the resonant frequency of a tensioned steel wire clamped between the diaphragm and the main body of the gage. Like the vibrating wire strain meter, contact resistance, leakage to ground or signal cable need only be continuous in order for a reading to be made. Signal cable lengths up to a mile can be used. The frequency readings are obtained with a portable digital readout meter. A variety of heads and filter permeabilities can be provided.

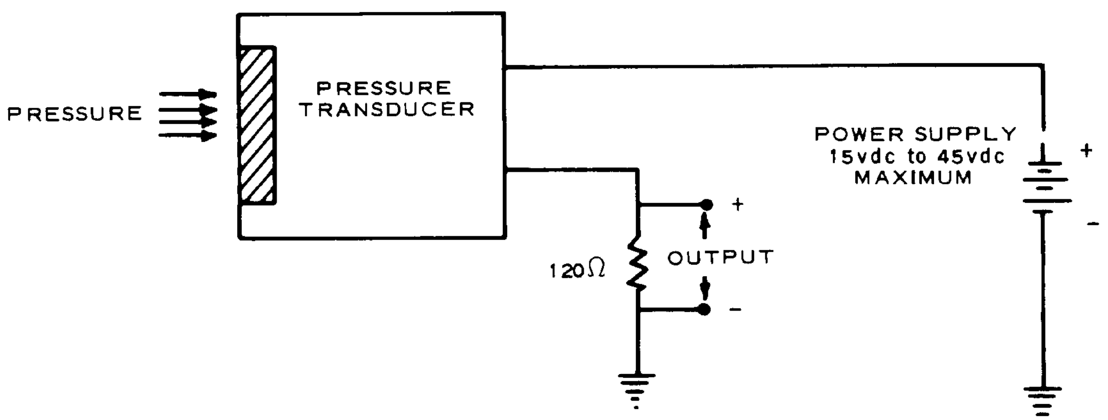
3-12. Strain Gaged Diaphragm Pressure Gage. There are now available some strain gaged diaphragm pressure gages that have the stability necessary for long time measurements. These gages can be useful for pore and uplift pressure measurements as utilized in the WES Telemetry system for measuring the pressure under a stilling basin slab and transmitting the data by radio waves at periodic intervals. The pressure gage used in the WES Telemetry system is the Bell and Howell 4-403 pressure transmitter. The current output instrument is a true 2-wire device with no moving parts, offering long-term stability under extreme environmental conditions. The instrument is temperature compensated over the range of O°F to +165°F. Since it is a current transmitter, relatively long electrical cable can be used without affecting its output. The simplified measuring circuit and gage configuration are shown in Figure 3-8a and b.

3-13. WES Pressure Measuring Telemetry System.

a. Transmitter and Gage. The WES Telemetry System was developed for measuring pressure under the stilling basin slab and transmitting this data out of the concrete slab, through the water and air to the receiving antennas on the structure. The transmitting package, Figure 3-8a, consists of: a Bell and Howell type 4-403 pressure transmitter, an A to D converter, conditioning system, a 100KHZ transmitter, lithium batteries, a stainless steel canister, and a ferrite rod antenna encased in plastic. The transmitting package is placed in a 7-in. drilled hole in the concrete slab with the pressure inlet end located at or near the bottom of the concrete slab and the top of the antenna located very near the top surface of the slab. After locating the package and sealing around the bottom of the canister with sand, the remainder of the hole is filled with a high strength grout.



a. Pressure Transmitter



b. Measuring Circuit

Figure 3-8. Strain Gaged Diaphragm Pressure Gage (Courtesy of Consolidated Electrodynamics).

b. Receiving System. The receiving system consists of a 100KHZ loop antenna connected to receivers with RG213 coxial cable, receivers with microcomputers, data logger with microcomputer, and a printer. The BCD pressure data are transmitted at 30-minute intervals. The receivers hold the previous data for approximately 29-3/4 minutes, clears the data, and waits for new data. The main logging system continuously scans the remote receivers and operates on the data to provide continuous reading of pressure or equivalent water elevation. The printer can be set to print the data at a selected time interval. Figure 3-9 shows the gage and transmitter in the foreground and the receiving system in the background. For more detailed information on this system contact the Structures Laboratory, Waterways Experiment Station, P. O. Box 631, Vicksburg, MS 39180.

3-14. Hydraulic Pore Water Pressure Cell.

a. Principle of Operation. Hydraulic Pore Water Pressure Cell, shown in Figure 3-10, is designed to provide a low cost piezometer for use in both embankments and foundations. The cell operates on the hydraulic relief principle which is precise, rugged, and reliable. Water in the soil or rock mass acts on the cell through a filter stone which covers an oil-filled chamber leading to a diaphragm. The pressure of the water acts on the diaphragm through the medium of a piston which is also acted on by a compression spring. Pressure on the diaphragm holds it flat against a pressure plate in which two small inlet ports are drilled. The inlet ports are connected by nylon or steel tubing to the readout station. At the readout station, the tubing is connected to a hydraulic pump. This instrument is available from Terrametrics, 16027 West Fifth Avenue, Golden, CO 80401.

b. Reading. To read the pore water pressure, one inlet port is pressurized until the diaphragm lifts off the pressure plate, When this occurs, the oil escapes for one inlet port across to the other and bleeds back to the oil reservoir. Additional operation of the pump causes no further increase of pressure. The pore pressure is then calculated by the simple formula:

$$P = G + H - S$$

where P is the pore water pressure, G is the maximum attainable gage pressure (occurs when diaphragm lifts), H is the hydraulic head in the inlet port tubing, and S is the spring pressure.

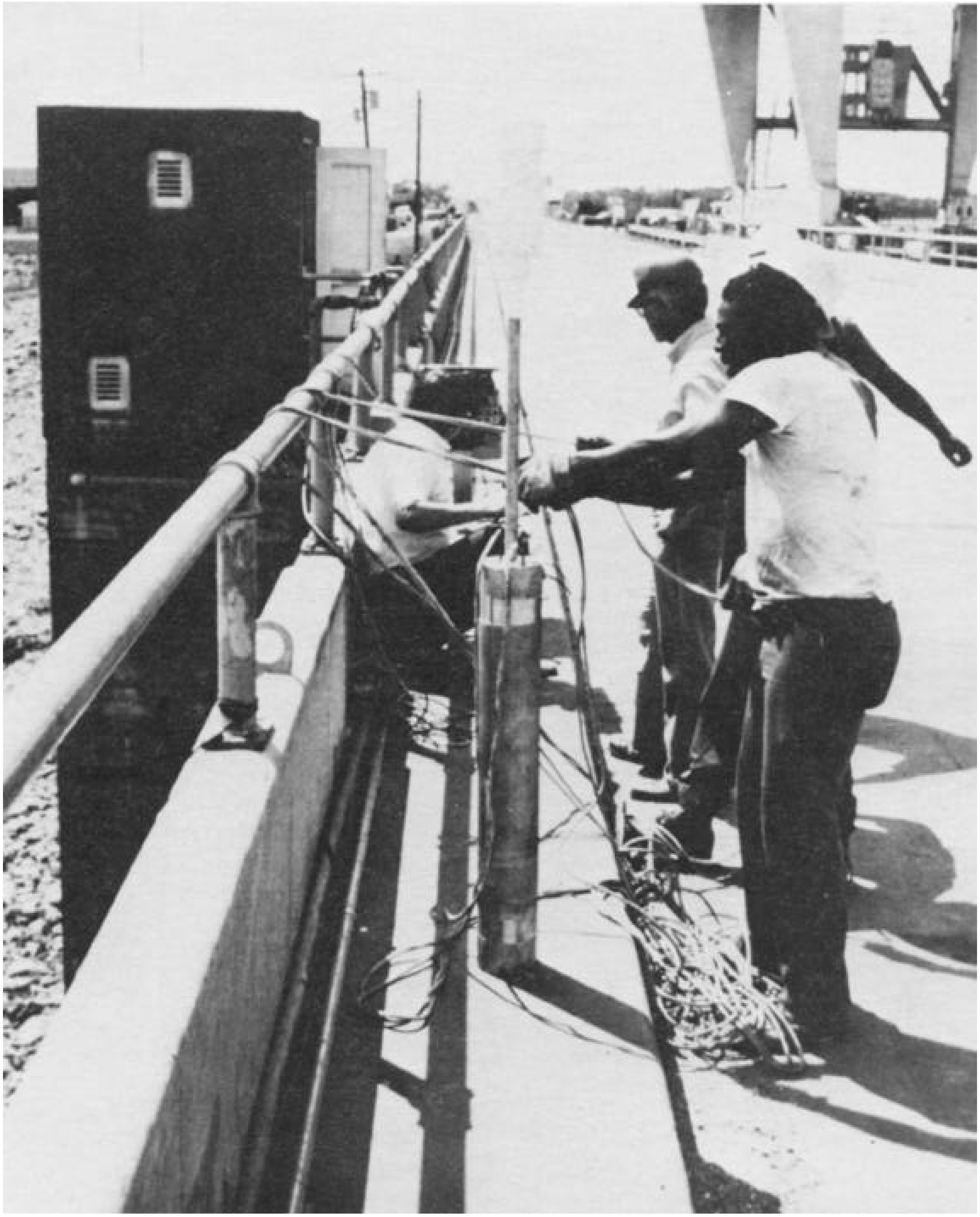


Figure 3-9. WES Pressure Measuring Telemetry System. (Photo by WES)

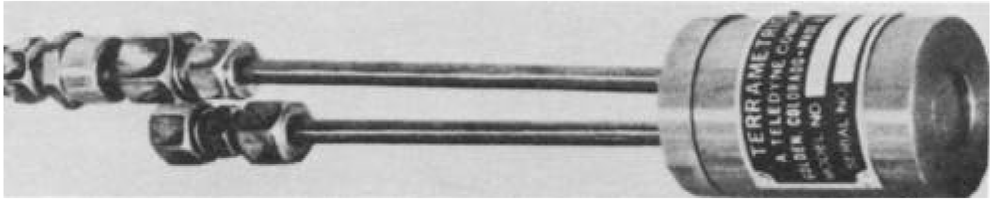


Figure 3-10. Terrametrics Pore Water Pressure Cell (Courtesy of Terrametrics, Inc.).

3-15. WES Hydrostatic Pressure Cell. A hydrostatic pressure cell for measuring pore water pressure in concrete is available from the Operations Branch, Instrumentation Services Division of the Waterways Experiment Station, P. O. Box 631, Vicksburg, Mississippi 39180. Its principle of operation is the amount of electrical resistance generated in a full bridge electrical resistance strain gage circuit bonded to a metal diaphragm that reacts to water pressure on its face. As shown in Figure 3-11, the metal diaphragm is directly behind a porous stone in the instrument face. The pore pressure deflects the metal diaphragm inducing strain which is proportional to the pore pressure at the face of the meter. Readings are taken with a standard strain indicator such as the Carlson test set or Biddle strain gage indicator.

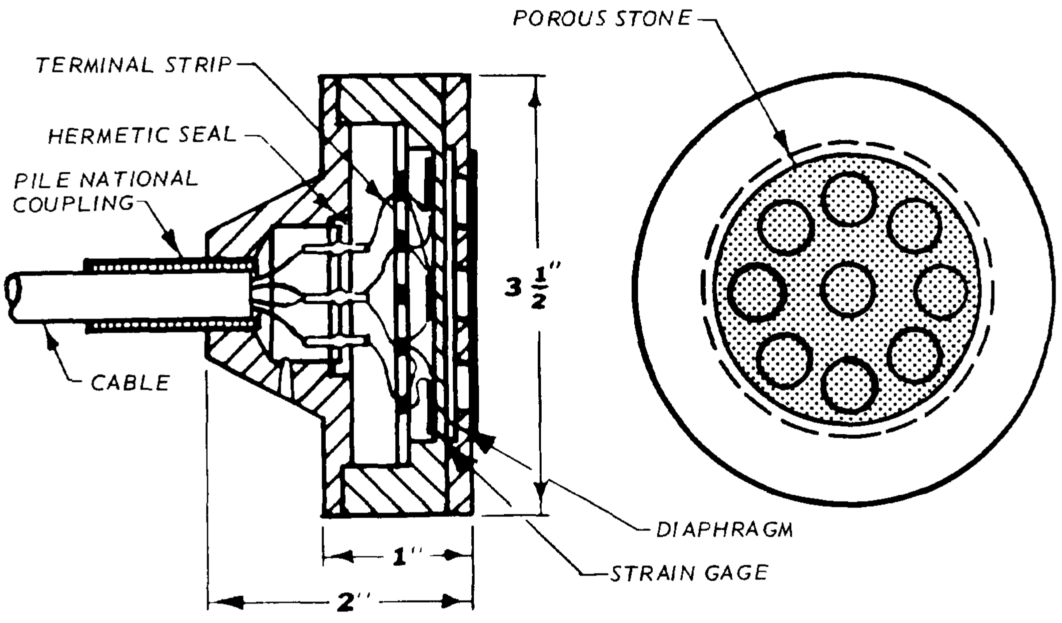
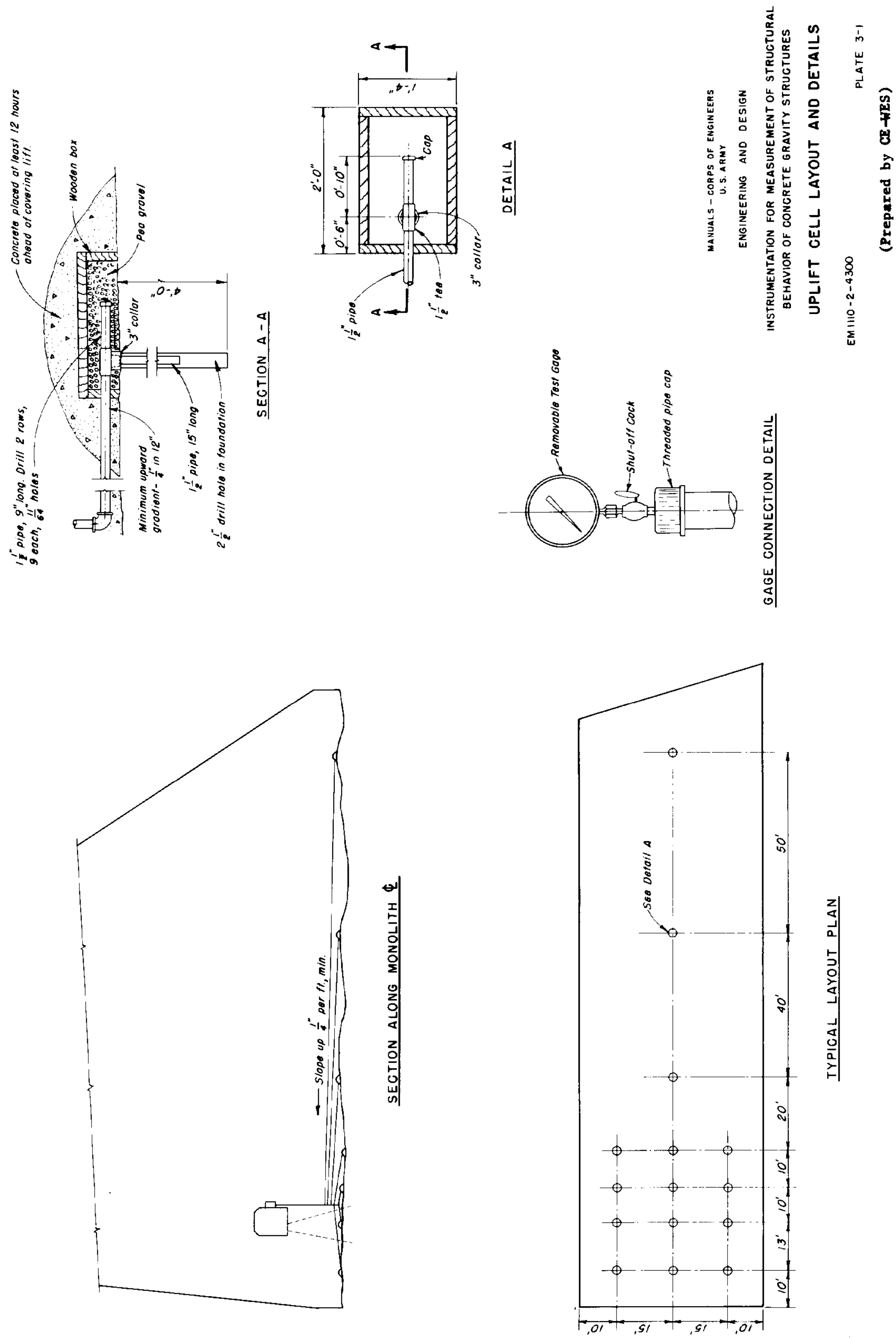


Figure 3-11. WES Hydrostatic Pressure Cell. (Drying prepared by WES)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ENGINEERING AND DESIGN
INSTRUMENTATION FOR MEASUREMENT OF STRUCTURAL BEHAVIOR OF CONCRETE GRAVITY STRUCTURES
UPLIFT CELL LAYOUT AND DETAILS
EM 1110-2-4300
PLATE 3-1
(Prepared by CE-WES)
SECTION A-A
Concrete placed at least 12 hours ahead of covering lift.
Wooden box
Pea gravel
3" collar
4'-0"
1 1/2" pipe, 9" long. Drill 2 rows, 9 each, 11/64" holes
Minimum upward gradient- 1/4" in 12"
1 1/2" pipe, 15" long
2 1/2" drill hole in foundation
DETAIL A
2'-0"
0'-10"
0'-6"
1'-4"
Cap
3" collar
1 1/2" pipe
1 1/2" tee
A
GAGE CONNECTION DETAIL
Removable Test Gage
Shut-off Cock
Threaded pipe cap
SECTION ALONG MONOLITH ℄
Slope up 1/4" per ft, min.
TYPICAL LAYOUT PLAN
See Detail A
50'
40'
20'
10'
10'
13'
10'
10'
15'
15'
10'

Plate 3-1

FOUNDATION UPLIFT PRESSURES

DAM	CELL	MONOLITH
LOCATION		
ELEVATION OF CELL	ELEVATION OF READING STATION	

DATE	TIME	PRESSURE AT READING STATION		PRESSURE GRADIENT ELEVATION	RESERVOIR W.S. ELEVATION	TAILWATER ELEVATION	PRESSURE HEAD AT CELL *(Feet)*	HEIGHT OF RES. W.S. ABOVE CELL *(Feet)*
		P.S.I.	*HEAD *(Feet)*					

* *WHEN NO PRESSURE EXISTS, RECORD DISTANCE TO W.S. IN PIPE AS NEGATIVE VALUE.*

ENG FORM 1 MAR 53 2254

SHEET ____ OF ____ SHEETS

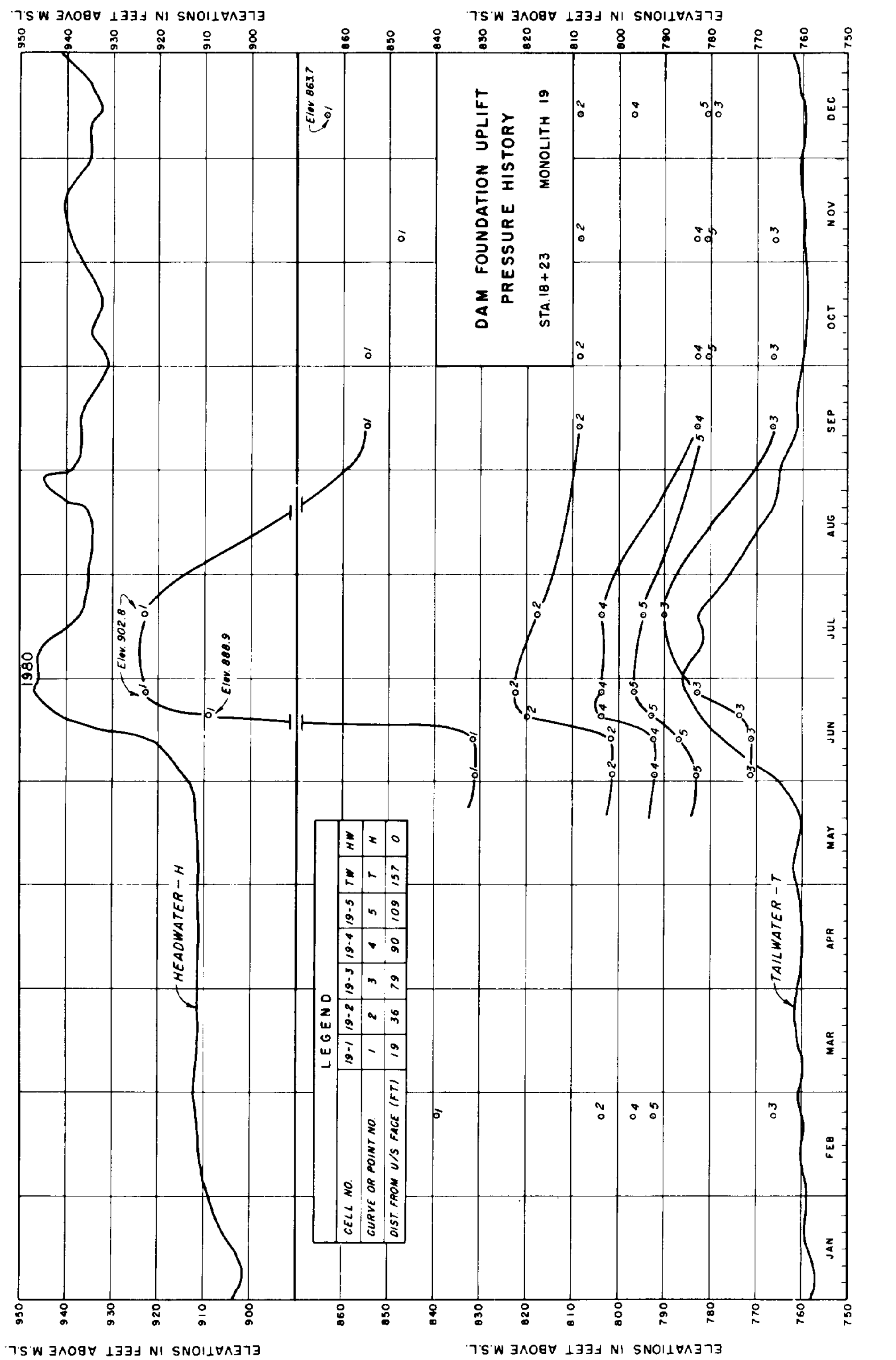
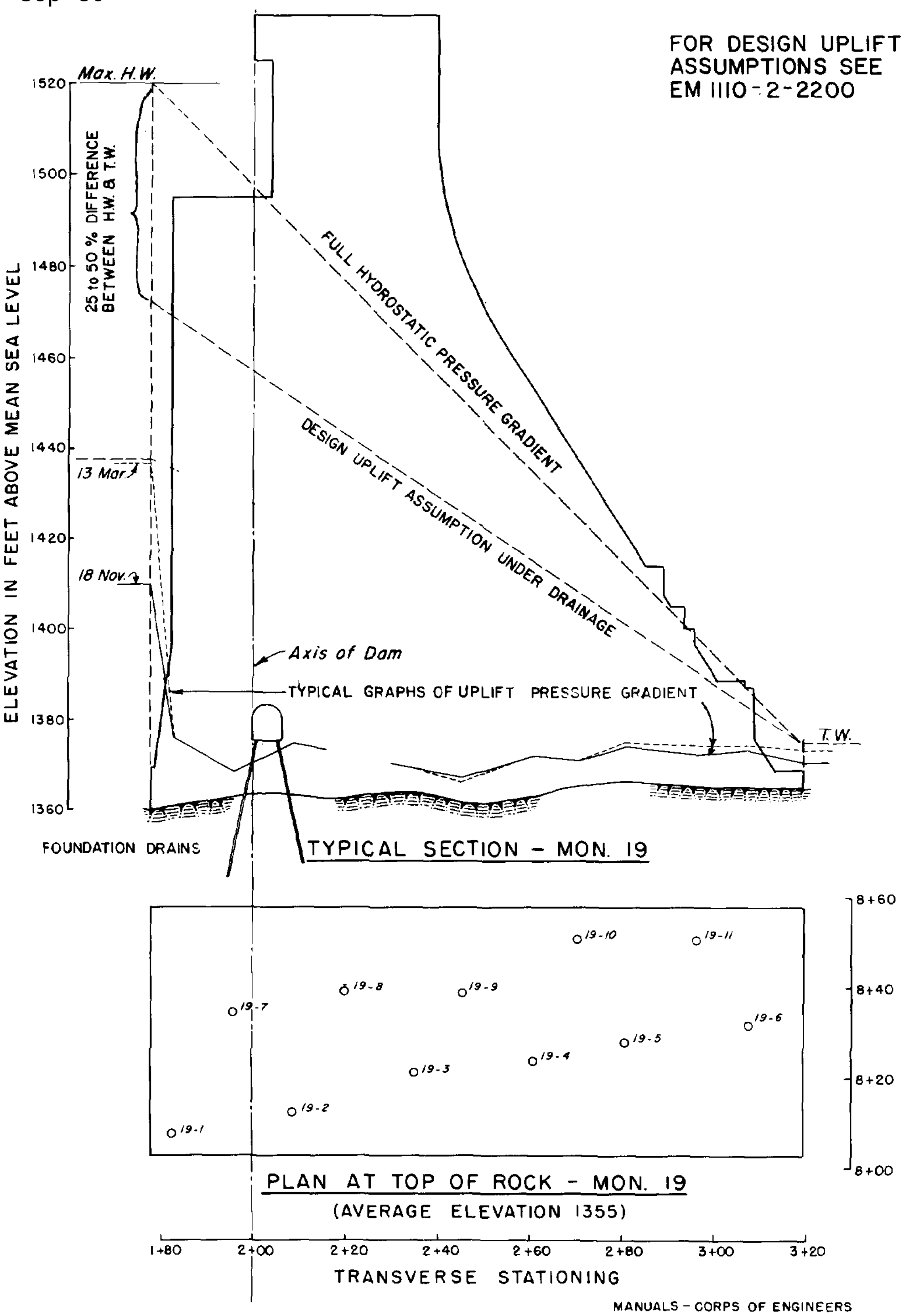


PLATE 3-3

(Prepared by CE)

Plate 3-3



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ENGINEERING AND DESIGN

INSTRUMENTATION FOR MEASUREMENT OF STRUCTURAL BEHAVIOR OF CONCRETE GRAVITY STRUCTURES

METHOD OF SHOWING
UPLIFT PRESSURE GRADIENTS

EM1110-2-4300 PLATE 3-4

(Prepared by CB-WES) Plate 3-4